

Testbed for Evaluating Automated C2 Decision Models

*Mary L. Cheek
James C. Eamon*

Joint National Test Facility
730 Irwin Avenue, Room 270
Schriever Air Force Base, CO 80912-7300
mary.cheek@jntf.osd.mil, james.eamon@jntf.osd.mil

ABSTRACT: *The Joint National Test Facility at Schriever AFB is developing a next generation C4I simulation for analyzing the performance and operational concepts of future ballistic missile and air defense systems. An important component of this simulation is the representation of a realistic automated command decision-making process, or the “Simulated Commander.” This paper describes a software testbed that was developed and used to evaluate different approaches to implementation of this component. The testbed consists of three components: a generic Battle Manager that provides battlefield situational data, a Simulated Commander model for evaluating various decision methods, and a GUI that displays the activities within these components and the communications between them. Since several aspects of human representation in C2 decision making for military simulations are currently being researched, the testbed design is flexible and extensible to allow testing of emerging techniques. The testbed architecture provides a convenient means of demonstrating how an automated battle manager interfaces with the Simulated Commander component of the wargame simulation. The three major components of the testbed are isolated from each other using well-defined interfaces to allow for easy “plug-and-play” capability, while enhancing re-use and porting of the various components*

1. Introduction

The Joint National Test Facility (JNTF) is the arm of America’s Ballistic Missile Defense Organization (BMDO) dedicated to ensuring the integration, interoperability, and effectiveness of America’s missile and air defense systems. The JNTF provides expert Modeling and Simulation (M&S), analysis, testing, wargaming, and exercise support to the Department of Defense (DoD), joint, individual service, and international acquisition and warfighting communities. Several of these objectives will be met with the development of new joint service multilevel real-time wargame simulation called Wargame 2000 (WG2K). In the conduct of WG2K, a considerable number of players are required, many of whom travel to the JNTF from distant locations. Allowing the “players” to participate from their home locations by using remote terminals and established communication nets substitutes human travel for purchased hardware and communications costs. In some situations, this is cost effective; however, many people are still required to devote considerable time in every conducted wargame. This is especially true if the wargame is focused on

some particular role, then the other “players” function to keep the test realistic with little benefit to the majority of the participants. Selectively replacing human participants with Simulated Commanders is an approach that could alleviate the monetary and human costs while still providing realistic “players” for a wide range of wargame functions.

WG2K has requirements for fully automated command decision-makers that realistically represent human commanders at any level in the command hierarchy of a joint services Ballistic Missile Defense (BMD) wargame. To meet his need, it was apparent that some form of testbed would be helpful in evaluating the various simulated commanders, from the missile battery commanders to the CINC level. A prototype Simulated Commander representation of a mid-level BMD decision-maker was developed and demonstrated since near-term project milestones involved this domain. BMD domain selection was fortuitous as a simplified BMD automated battle manager, a crucial adjunct in the command decision process, was also available that was compatible with the WG2K parallel discrete event simulation framework.

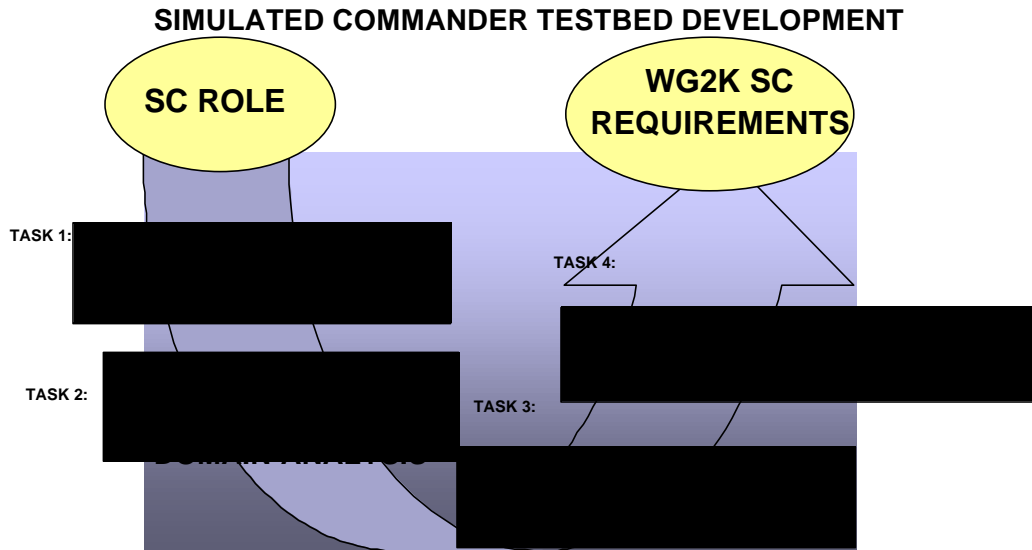


Figure 1 WG2K Simulated Commander Support Tasks

2. Approach

The final testbed development (Figure 1) was part of a larger task to support the wider requirements of WG2K. The first task was to investigate a number of existing wargame simulations to determine their potential reuse as the SC element of WG2K. This effort revealed that no single application fully encompassed our problem space, so that we were not able to simply choose an existing simulation (such as ModSAF) that met our needs. The second task was directed at an evaluation of several expert system tools that appeared to be possibly applicable to the more complex higher echelon decisions of a WG2K commander. A research effort was accomplished in task 3 to explore the decisions, processes, interactions, and knowledge base to support development of a Simulated Commander in a BMD domain. In this task, the analysis included evaluation of AI techniques that may support those decisions specifically required by the WG2K simulation.

In the final task, which is the primary subject of this paper, the elements of the first three tasks were drawn upon to develop a prototype demonstration of several WG2K SC interfaces and decision requirements. In this demonstration, we used as a basis some of the concepts in the DARPA Synthetic Theater of War Command Forces (STOW/CFOR) model architecture, in which the decision-making processes are kept separate from the simulated

environment. Models from knowledge acquisition and data representation are still a developing discipline. The decision-making processes of the WG2K SC will likely require the utilization of various AI technologies. The SC prototype demonstrates the feasibility of applying these techniques as external routines.

3. Analysis of Expert System Models for Higher Level Decision Processes

The SC element of WG2K requires a wide range of command decisions. The lower level (e.g. tank commander) decision processes is usually very structured and rule-driven. It is possible that this portion of the WG2K SC will rely on some existing simulation, such as EADSIM or ModSAF to provide the necessary CGF behavior. At the mid- and high-echelon decision levels, however, the decision process is likely to involve more information, more options, complex decisions, and often incomplete or ambiguous perceived situational data. It was our recommendation that such decision processes might be best simulated using Artificial Intelligence (AI) techniques, and in particular Expert System (ES) methods. We conducted a review of some of the more widely used ES tools. While some of these tools have been used in other projects to represent military command and control decision processes (SOAR and CLIPS), none were found to have been applied in the specific domain of ballistic missile defense in which we were most interested.

In our assessment of off-the-shelf Expert System tools, we considered a number of factors. These included:

- Cost
- Ease of coupling with an object-oriented simulation
- Feature richness of the candidate ES, including rule limits and fuzzy reasoning capability and the number of different types of inference techniques available
- Ease of integrating the tool into other simulations
- Technical Support – The availability of technical support including documentation on the candidate.
- Market share, an estimate of the share of the ES market the tool has captured (often related to the maturity of the system)
- Ease of use, including setup and rule development. The extent of the development environment was considered, including debugging aids, on-line help, and an integrated editor.

As a result of our evaluation, we found that the FuzzyCLIPS tool held the most promise for our application in missile defense simulation decision making.

4. Understanding the Ballistic Missile Defense Command and Control Domain

While the Expert System tools may provide the foundation of a C2 Simulated Commander, a major challenge in applying any of these tools is in developing the necessary domain knowledge base and understanding the details of the decision processes. This task was an effort directed toward understanding the ballistic missile defense C2 decision process. Much of this effort was focused on the TAMD regime, but nearly all of it is applicable in a general manner to the decision processes in NMD scenarios.

The use of a rule based Expert System assumes that expert knowledge can be extracted and represented by rules. The goal of SC is to provide an intelligent stand-in player for any

mid- to high- echelon commander in a TAMD or NMD scenarios. The knowledge base for even a single high-level simulated decision-maker can be huge. To better understand some of the details of the process, we chose to concentrate on a Patriot Battalion Commander. Many of the elements in the implementation of the simulated decision process will be directly comparable to a mid-level commander in an NMD game scenario. We sought to acquire general baseline knowledge such as doctrine and mission understanding before turning to specific experts for more heuristic knowledge. The best sources for background information are the Army Doctrine and Training Digital Library (ADTDL) website, the Joint Doctrine website, and the Functional Description of the Battlespace (FDB) website. We plan to use this information to develop a set of operating procedures that the heuristic rules will initiate.

An important aspect of the simulated command decision process involves communication. The SC will need to communicate with other players, human and simulated, through an interface with the Battle Manager. We examined the formats and usage of reports and orders used in the Joint Operations Planning and Execution System (JOPES). We also examined the Command and Control Simulation Interface Language (CCSIL) for possible reuse. We created a partial data dictionary of CCSIL to identify those structures pertinent to missile defense.

The overarching philosophy that guided our effort was the concept of a decision-centered methodology (Figure 2). The mission requirements were translated into a scenario to provide a concrete foundation for understanding and visualizing the TAMD domain. Requirements were allocated to processes. We choose JOPES for process modeling because it is widely used by the United States military. The focus of our effort was the TAMD Patriot Missile Battalion Commander. This processing thread is rich enough to provide interesting rules and algorithms for the simulated commander to execute (Figure 3). We concentrated further on the “Execute” phase and three subtasks: monitor, assess, and replan.

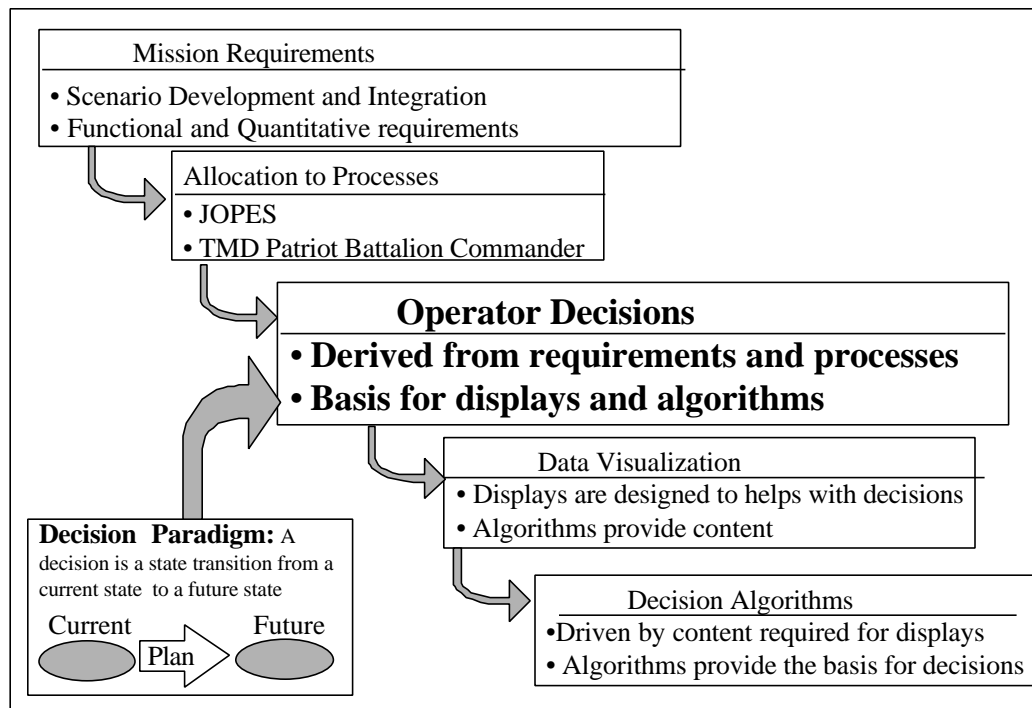


Figure 2 – Decision-Centered Methodology

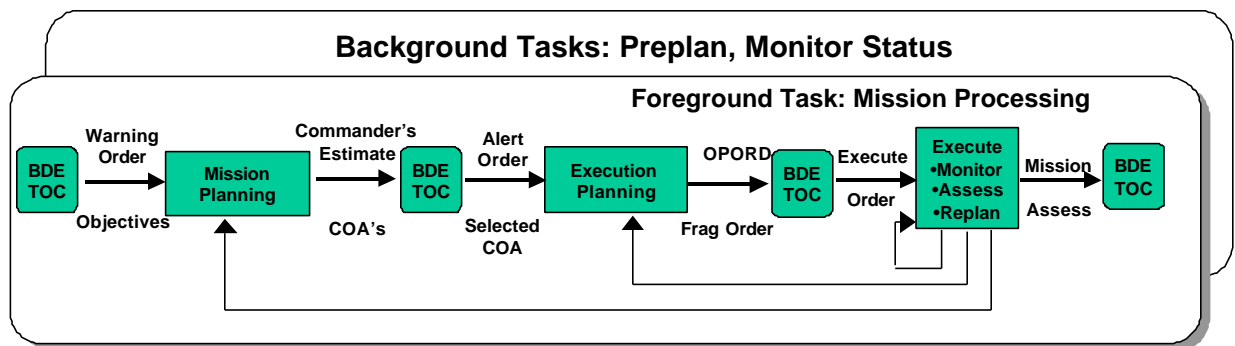


Figure 3 - JOPES Processing Thread

Since the SC is an automated human decision maker, it is a surrogate or substitute for the human commander. The automated decision process modeled in the Simulated Commander must use the same information that is supplied to a human counterpart. We envision the simulated commander to gain his perception of the battlefield primarily from information supplied by the Battle Manager, as is the case for a human commander. In the case of the SC, this information is gained through a software

interface. The SC does not interface directly with the sensors or weapons; information and data flow through the BM. A real human commander receives situational data from visual displays of the automated Battle Managers and from other sensory inputs. In the case of an SC, this data must come via an interface with the Battle Manager, as illustrated in Figure 4. In our concept, the SC element is external to the main simulation component, while the Battle Manager is integral with it. Information flow from the BM to the SC is handled through a socket connection

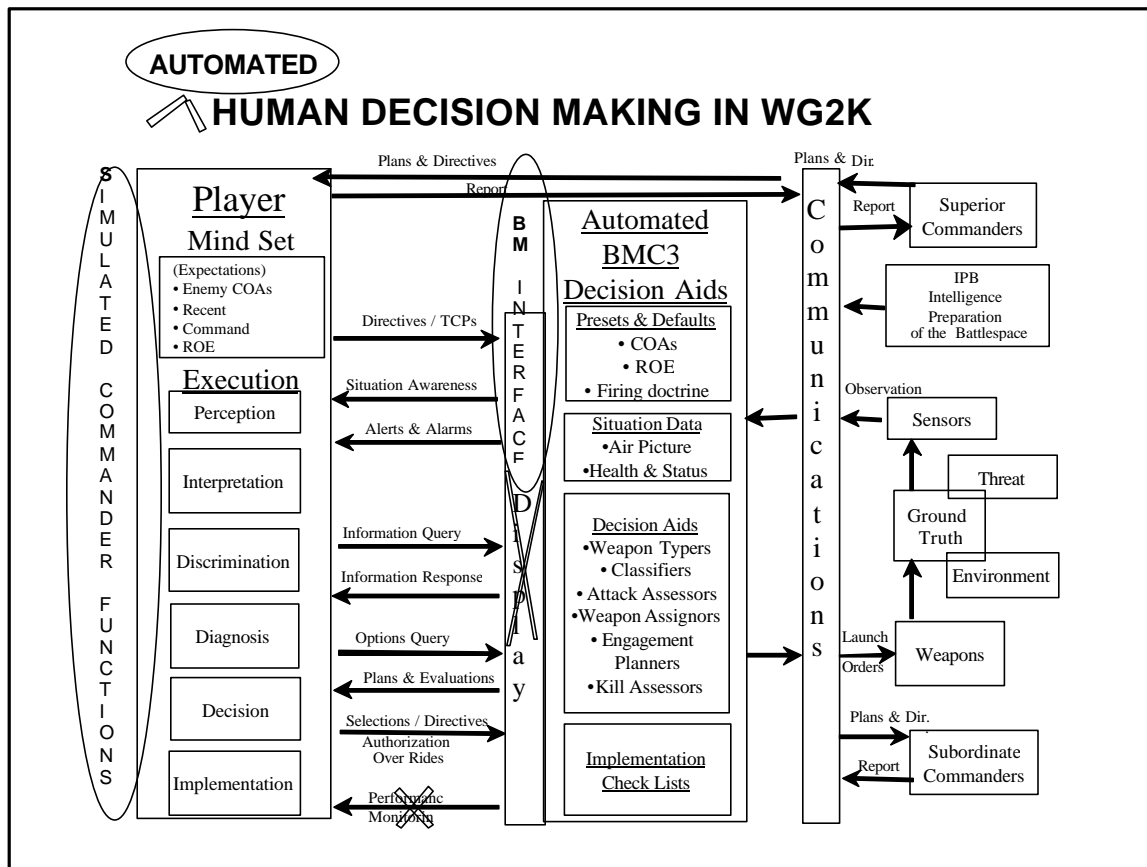


Figure 4 – Human Decision Making in WG2K

In a future implementation, we may explore the use of HLA as the means to effect this interface

5. Development of a Simulated Commander Demonstration Testbed

The preceding task efforts provided the foundation for our primary task -- the development of an SC demonstration testbed that interfaces with a representative missile defense battle planner, implements Expert System decision methods, and illustrates realistic decision processes.

Many of the elements of a C2 decision process are the same whether implemented in a TAMD or NMD scenario. For the demonstration, we chose NMD for several reasons. First, WG2K's initial deliveries are to support NMD games, and therefore the Battle Manager's interface is more clearly defined. Second, the decisions expected of a commander in NMD are simpler and require

fewer algorithms. Third, we were able to use an existing NMD battle planner that runs as an application of the WG2K parallel discrete event simulation (PDES) framework, called SPEEDES. The demonstration testbed proved the feasibility of integrating a virtual environment with a separate decision-making system. This is reflected in the demonstration by using the Los Alamos National Labs Battle Planner (LANL BP) to provide automated battle planning data with the PROX functional NMD model providing the virtual environment, and by using FuzzyCLIPS as the decision processor. The LANL BP and the PROX models are test drivers provided with the PDES used in WG2K, namely SPEEDES.

The testbed concept consists of three components shown in Figure 5.

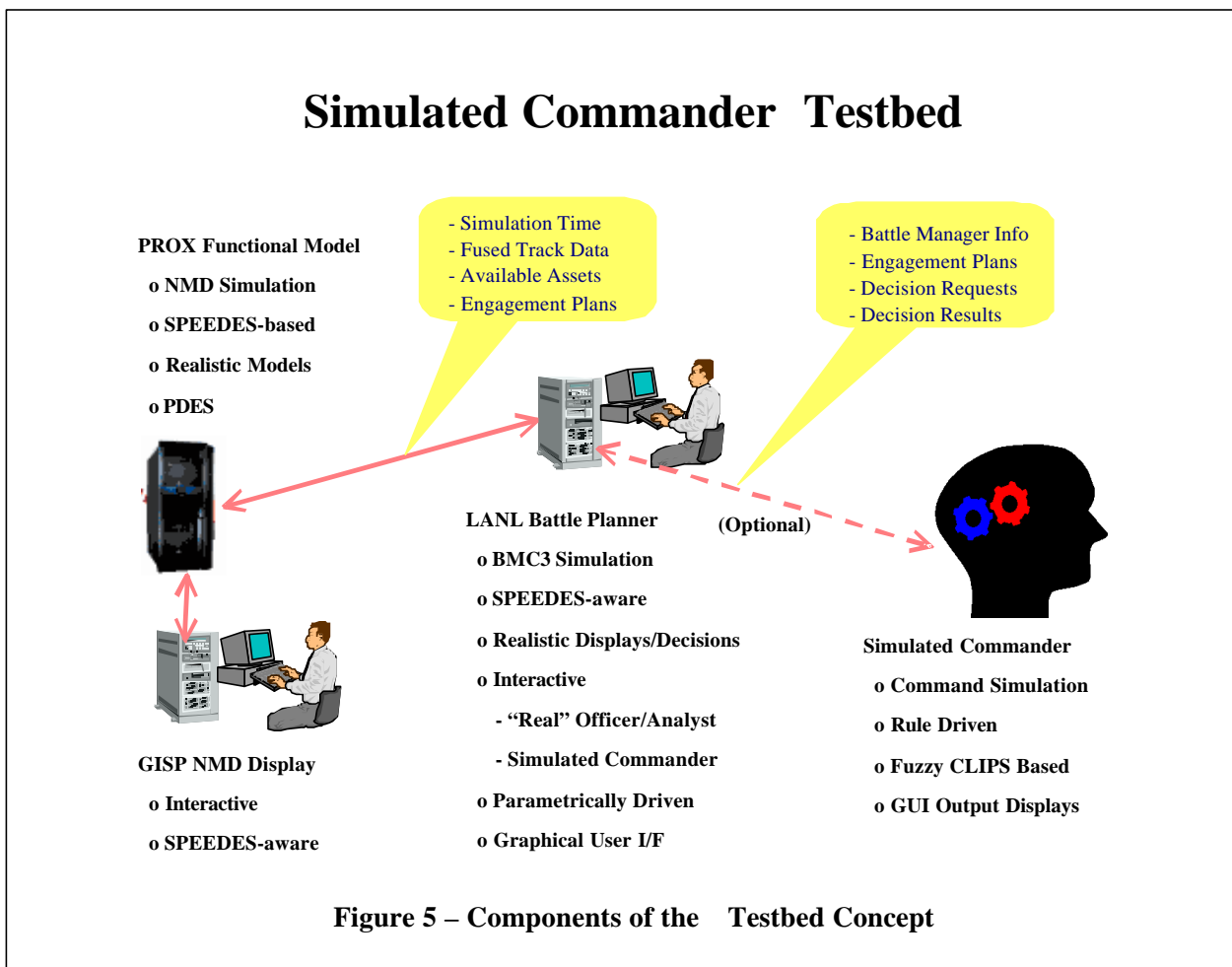
- On the left is the PROX Functional Model, a low to medium fidelity missile defense simulation that is packaged with the SPEEDES framework demo, so it works

with SPEEDES in a PDES fashion. It flies threat missiles and aircraft, uses sensors to detect them, passes the information to C2 facilities, fires interceptors, and provides the user with a global view of the situation with missile tracks, sensor coverage cones, etc. The GUI interface is through the SPEEDES Host Router.

- LANL BP, a low to medium fidelity battle planning model, also packaged with the SPEEDES demo. The LANL BP uses the threat, sensor, and defensive asset data to plan engagements. In the normal SPEEDES demo, the engagement plans are sent back to PROX for implementation.
- The SC component is shown on the right.

In our SC demonstration testbed, we have added two interfaces to the LANL BP to allow interaction with either a simulated or real commander. These are:

- (1) a GUI (called GISP National Missile Defense (NMD) Display shown as the solid arrow on the left in the figure) to the LANL BP that provides situational data, recommended engagement options, etc. to a human player, and
- (2) a UNIX socket connection to the third (and principal) portion of the testbed, the Simulated Commander element (dotted arrow in the figure).



The GISP NMD GUI provides an interface with the LANL BP that allows a real human player to be presented with threat track data, expected target data, interceptor inventory and status and other information. The display is based on one of the primary NMD Battle Management Command, Control, and Communications (BMC3) Capability Increment 3 (CI3) displays. Recommended engagement planning data are presented to a real player if present for confirmation, override, or no action. These include data such as current Defense Condition (DEFCON) level, Readiness Posture (RP), Rules of Engagement (ROE), and Mission Objective (MO). The real commander can change these depending on his assessment of the attack.

The second message-based interface to the LANL BP (dotted arrow in the figure) was built to interact with the Simulated Commander element of the testbed. Here a translator converts the BP data to a form useable by the decision algorithms, and calls the Expert System decision routines. The message set consists of 17 messages to provide information to SC that will trigger SC decision-making. Currently we are using the expert system shells C Language Integrated Production System (CLIPS) and Fuzzy CLIPS as candidates for some of the higher-level command decision-making. These are Expert System applications. CLIPS was originally built by National Aeronautical and Space Administration (NASA). The translator will create or make changes to an instance of a message object. It will determine which SC the message is for and pass the message to that SC. An SC is represented in FuzzyCLIPS as a module. A module in FuzzyCLIPS encapsulates its own fact list, rule set, and agenda. Modules can be defined to share particular elements selectively, so messages can be sent to multiple SCs. The SC element processes the battle management data and returns the decision information back to the LANL BP for implementation. We also are planning to implement a GUI display driven by the SC that provides a textual illustration of some of the rules firing and decisions reached. FuzzyCLIPS has Facts and Agenda Xwindows that can be called. The two interfaces to the LANL BP allow either a human or simulated commander player.

The SC demonstration testbed runs a BMD vignette and demonstrates expected decisions.

The decisions and rules used in the testbed are very simplistic, but demonstrate feasibility of the concept. The SC demonstration was built to make six specific BMD command decisions:

- DEFCON level 1 through 5
- Defense Engagement Authorization (DEA) -
- Weapons Free or Weapons Hold
- Readiness Posture (level 1 or 2)
- Mission Objectives (Current or Alternate)
- Battle Plans (choice of two)
- Rules of Engagement (ROE) -- choices are Continental United States (CONUS), North America,, US, Test Range, and Max Defense

The knowledge base contains rules to assign authorization for an SC, depending on identity, to make these decisions. In reality, the DEFCON decision is a complex one. The information to the demonstration testbed to make this decision is extremely limited compared to what the human commander would have. During training for the wargame, the human player will get intelligence information about the world situation, including numerous factors. We were unable to obtain a list of these factors. The priority was not urgent, but this type of information will be necessary for the SC to make intelligent decisions. We plan on using tools such as the Fuzzy Decision Trees to help the software make sense of the information. The DEFCON decision is based on current DEFCON level, ROE assessment, and threat assessment. The external algorithms for ROE and threat assessment were not employed for the prototype. The rules needing the assessments instead called external routines that returned hardcoded values. The DEA decision was based on ROE criteria being met. Readiness posture decision was based on perceived threat (hardcoded), weapons available, and internal problems with system (hardcoded). The decision tested SC ability to play multiple hierarchical roles. The decision to change Mission Objectives from Current to Alternate is based on probability of mission success.

6. Summary

In support of requirements at the JNTF to provide a automated decision making entity for wargame simulations in the missile defense domain, a number of tasks were completed

culminating in the development of a testbed for evaluating various concepts.

Future efforts are planned to further flesh out the decision process in the Simulated Commander component of the testbed, shifting our focus from NMD to the Theater Air and Missile Defense (TAMD) domain. The quality of an Expert System is only as good as its knowledge base. It is risky to proceed with an Expert System without an experienced knowledge engineer. One way to mitigate some of this risk is to use validated models; several of these were found on the FDB website. Subject matter experts can also validate the models against official doctrine. We plan on much additional effort aimed at developing the necessary knowledge base to support our continuing SC effort. We plan to conduct interviews with a Patriot Battalion Commander from Ft. Bliss, TX, perhaps using Knowledge Acquisition Tools. There is a higher probability of obtaining a quality system associated with the use of these tools.

We are coordinating our SC concept development efforts with the WG2K Battle Manager developers. SC decisions for TAMD that weren't applicable in the NMD scenario include deconfliction, target prioritization, planning, and coordination. Decisions in TAMD will also require more processing because a

TAMD Battle Manager is not central to the complete battle scene. Human players will share staff resources and conduct briefings. This information will also need to be represented in a future version of the SC.

Author Biographies

JAMES C. EAMON is a Senior Analyst in the Technology Insertion Studies and Analysis Delivery Order at the JNTF. He is the technical lead for development of a Simulated Commander concept for the WG2K simulation and has developed PDES performance analysis tools for both NMD and TAMD scenarios. Mr. Eamon has 25 years experience in missile defense analysis, software development, and program management. Education: BS Physics

MARY L. CHEEK is an engineer for the Technology Insertion Studies and Analysis (TISA) Delivery Order at the JNTF and a principal member of the TISA Simulated Commander development team. She is responsible for developing the TAMD knowledge base and rules for simulating command behavior. Ms. Cheek has taken training courses in the CLIPS expert system tool. Education: MA. Mathematics, additional coursework in Statistics, and Computer Science